

Evaluation of different minimally invasive techniques in the surgical treatment of atrial septal defect

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Objective: Minimally invasive cardiac surgery is becoming a safe and cosmetic alternative to standard median sternotomy (SMS). In the present retrospective study, we reviewed our results and experience with the totally thoracoscopic (TTS) and right vertical infra-axillary thoracotomy (RVIAT) techniques for atrial septal defect closure compared with SMS.

Methods: From December 2010 to February 2012, 198 patients underwent repair of atrial septal defect using the TTS technique (n = 66), RVIAT (n = 59), or SMS (n = 73). Cardiopulmonary bypass was achieved peripherally in the TTS group and directly in the RVIAT and SMS groups.

Results: The procedures were performed successfully in all 3 groups, and no in-hospital mortality occurred. No patient required conversion to SMS in the TTS group, although 2 patients did so in the RVIAT group. The cardiopulmonary bypass time was 87.26 ± 21 minutes in the TTS group, 41.81 ± 13.97 minutes in the RVIAT group, and 36.99 ± 10.84 minutes in the SMS group ($P < .01$). The crossclamp time was 32.86 ± 13.36 , 22.54 ± 9.08 , and 19.23 ± 6.92 minutes in the TTS, RVIAT, and SMS groups, respectively ($P < .01$). The total incision length in the SMS group (7.45 ± 1.54 cm) was longer than that in the other groups (TTS group, 5.21 ± 0.63 cm; RVIAT group, 6.48 ± 1.37 cm); the difference was statistically significant ($P < .01$).

Conclusions: The TTS technique and RVIAT can both be performed with favorable cosmetic and acceptable clinical results for closing atrial septal defects. They are promising alternatives to SMS and merit additional study. (J Thorac Cardiovasc Surg 2014;148:188-93)

Atrial septal defect (ASD) is one of the most common congenital heart diseases and constitutes 30% to 40% of all congenital heart diseases in adults.¹ Transcatheter closure of ASDs is standard practice, and excellent results have been reported, with low early and late complication rates.² However, primary surgical repair is still needed for large secundum defects with limited septal margins and complex ASDs, including ostium primum, sinus venosus ASDs, and fenestrated or aneurysmal interatrial septal.

With the assistance of advanced instrumentation and the rapid development of surgical techniques, the clinical results of cardiac surgery have dramatically improved during the past decade. Thus, the cosmetic and psychological implications of surgery have assumed increasing importance, and a variety of minimally invasive cardiac surgical techniques have been developed, including right

thoracotomy,³⁻⁷ port-access surgery,⁸⁻¹⁰ and video-assisted methods.¹¹

In our center, right vertical infra-axillary thoracotomy (RVIAT) has been used to repair congenital heart defects for several years to avoid standard median sternotomy (SMS) and its related discomfort. In addition, the totally thoracoscopic (TTS) technique has been performed for selected patients for the past 2 years. In the present retrospective study, we have reviewed our results and experience with the RVIAT and TTS techniques for the treatment of ASD compared with SMS.

METHODS

The institutional review board of Zhengzhou University approved the present study, which was in compliance with Health Insurance Portability and Accountability Act regulations and the Declaration of Helsinki. The institutional review board waived the need for individual patient consent. The selection criteria for TTS or RVIAT ASD repair at our department were as follows: (1) age ≥ 10 years, with a body weight of ≥ 20 kg; (2) pulmonary arterial systolic pressure as measured by echocardiography of ≤ 60 mm Hg; (3) no history of lung disease or surgery on the right side of the chest; and (4) no other cardiovascular disease or chronic illness. Patients who were unable to meet all these selection criteria or who were unable to give informed consent were excluded from the present study. All patients underwent ASD closure by the same surgical team.

From January 2011 to December 2012, 198 patients underwent elective ASD closure. In accordance with patient preference and after discussion in our cardiology and surgical conference, surgical access was done using TTS (n = 66), RVIAT (n = 59), or SMS (n = 73). The 3 groups were well-matched for age, weight, pulmonary/systemic flow ratio, and defect size (Table 1).

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Abbreviations and Acronyms

ASD	= atrial septal defect
CPB	= cardiopulmonary bypass
ICU	= intensive care unit
RVIAT	= right vertical infra-axillary thoracotomy
SMS	= standard median sternotomy
TTS	= totally thoracoscopic

Anesthesia

After induction of general anesthesia, a double-lumen endotracheal tube was placed to allow for single-lung ventilation in the TTS and RVIAT groups, and a single-lumen endotracheal tube was placed in the SMS group. The respiration rate was set at 18 to 30 breaths/min, and the arterial oxygen saturation rate was maintained at >97%.

Operative Technique

TTS group. For TTS, the patients were placed in the supine position with the right side of the body elevated 15° to 20°. A transesophageal echocardiographic probe was inserted routinely to assess the place of the venous cannulation and surgical result and to detect possible intracardiac air. Cardiopulmonary bypass (CPB) was established by peripheral arterial and venous cannulation. After systemic heparinization, a double lumen catheter was inserted through the right femoral vein into the inferior and superior venae cavae. A 2-cm incision was used at the inguinal fold to expose the femoral vessels. After an activated clotting time > 400 s had been achieved, direct arterial cannulation was usually achieved through the femoral artery. On the right side of the chest, three 1- to 2-cm incisions were made in the fourth intercostal space on the right side of the sternum, in the sixth intercostal space on a midclavicular line, and in the fifth intercostal space on the right midaxillary line. These incisions allow the entry of tissue forceps or suture needles, scissors, and an endoscopic camera or thoracoscope (Figures 1 and 2).

Pericardiotomy was performed once the 3 ports were secured, and 3 or 4 sutures were placed to suspend the pericardium. Caval snares were placed in the superior and inferior vena cava to install total CPB. Carbon dioxide was conveyed to the operative field through the third incision. A long perfusion needle was introduced through the third incision (port 3) and inserted in the aorta through the purse-string suture with the help of the thoracoscope. When core body temperature had decreased to 32°C, an aortic crossclamp was introduced through the third incision and occluded the ascending aorta under direct thoracoscopic view. After cardiac asystolic arrest with antegrade cold cardioplegia, the right atriotomy was opened from a site parallel to the atrioventricular annulus by the forceps and scissors through incisions 2 and 3, respectively, and 4 sutures were placed on the incision to expose the intra-atrial structure. The ASD type, size, and relation to the atrial structures were carefully identified. The ASD was closed with 4-0 Prolene suture directly or with a Dacron patch according to the size of the defect. De-airing was done from the perfusion cannula and the ASD defect before knotting by lung inflation. The right atrium was sutured using 4-0 Prolene after the aortic clamp had been released and body warmed. Carbon dioxide was removed after closing right atrium. The cannula was removed after weaning from CPB. A chest tube was placed from incision 1 to drain effusion and air.

RVIAT group. In the RVIAT group, the patients were positioned with the right side elevated 60°, and the right arm was placed over the head in a natural position. The skin incision began at the third intercostal space and extended to the fifth intercostal space along the right mid-axillary line (Figure 3) to form a right vertical infra-axillary incision. The length of the incision was approximately 5 to 9 cm, but varied depending on the patient's physical characteristics and type of lesion. The thoracic cavity

was entered through the fourth intercostal space. The lung was retracted posteriorly using wet sponges to expose the pericardium. The pericardium was opened 2 cm anterior to the phrenic nerve, superiorly to the pericardial reflection and inferiorly to the diaphragm, to provide enough exposure of the ascending aorta and inferior vena cava. After heparin sodium administration, the aorta was cannulated with the help of 2 long vascular clamps. One clamp was used to draw the cannulation site down and the other held the top of the aortic cannula to push it in place. Next, the superior and inferior venae cavae were cannulated. CPB with mild hypothermia (32°C) was instituted (Figure 4). An aortic perfusion needle was inserted in the aorta through the purse-string suture. Next, the aorta was crossclamped, and cold blood cardioplegic solution was used for myocardial protection.

After snaring the superior and inferior venae cavae, the right atrium was opened from a site parallel to the atrioventricular annulus, and 2 sutures were placed to expose the intra-atrial structure. The ASD was closed with direct 4-0 Prolene sutures. The autologous pericardium was used to repair larger ASDs with running Prolene sutures. The method of de-airing was the same as that for the TTS group. Once the CPB had ceased, the chest and pericardium were drained. The pericardium was closed, and all skin incisions were closed intracutaneously.

SMS group. In the SMS group, a standard midline sternotomy with a short skin incision was performed. Extracorporeal circulation was applied with venous outflow through catheters in both venae cavae, with arterial return through a catheter in the ascending aorta. Mild systemic hypothermia to 32°C was maintained. Myocardial protection was achieved with antegrade cold oxygenated blood cardioplegia and topical hypothermia. The exposure of the intra-atrial structure and the method of ASD closure were the same as described for the TTS group. The method of de-airing was also the same. Once CPB had ceased, the chest and pericardium were drained. The pericardium was closed, and all skin incisions were closed intracutaneously.

Postoperative Management

Postoperatively, the patients were monitored in the intensive care unit (ICU). Bedside chest radiography was performed in the ICU to exclude complications in the lungs. Mechanical ventilation was withdrawn when patients' hemodynamics became stable.

Statistical Analysis

The data were managed and analyzed using Statistical Package for Social Sciences, version 13.0 (SPSS, Chicago, Ill). All continuous variables are expressed as the mean \pm standard deviation and were compared using 1-way analysis of variance. The categorical variables were analyzed using the chi-square test. All statistical tests are 2-tailed. $P < .05$ was considered statistically significant.

RESULTS

Demographic and Clinical Characteristics

The patient characteristics and procedure-related variables were similar. Of the 198 patients, 66 (42 girls and 24 boys; mean age, 29.68 ± 12.17 years) were in the TTS group, 59 (36 girls and 23 boys; mean age, 29.27 ± 14.23 years) were in the RVIAT group, and 73 (34 girls and 45 boys; mean age, 27.08 ± 12.32 years) were in the SMS group. More girls were in the TTS (63.6%) and RVIAT (60.02%) groups than in the SMS group (43.03%, $P = .02$). However, no significant difference was found between the TTS and RVIAT groups. No significant differences were present among the groups in the

TABLE 1. Clinical patient characteristics

Variable	TTS group (n = 66)	RVIAT group (n = 59)	SMS group (n = 73)	F/chi-square value	P value
Mean age (y)	29.68 ± 12.17	29.27 ± 14.23	27.08 ± 12.32	0.82	.44
Gender				7.42	.02
Female	42 (63.6)	36 (60.02)	34 (43.03)		
Male	24	23	45		
Weight (kg)	48.31 ± 14.8	50.11 ± 11.55	51.17 ± 9.71	0.97	.38
Qp/Qs	2.24 ± 0.29	2.21 ± 0.37	2.16 ± 0.38	0.85	.43
Defect size (cm)	2.62 ± 0.82	2.71 ± 0.7	3.04 ± 2.43	1.37	.26

Data presented as mean ± standard deviation or n; data in parentheses are percentage of female patients of the total for each group. TTS, Totally thoracoscopic; RVIAT, right vertical infra-axillary thoracotomy; SMS, standard median sternotomy; Qp/Qs, pulmonary/systemic flow ratio.

pulmonary/systemic flow ratio or defect size. The 3 groups were comparable in the patient characteristics and procedure-related parameters (Table 1).

Perioperative Profile

The procedures were performed successfully in all patients in the 3 groups, and no in-hospital mortality occurred. No patient required conversion to SMS in the TTS group, although 2 patients required conversion to SMS in the RVIAT group. Immediate transesophageal echocardiographic analysis after ASD repair in all patients showed complete closure with no residual shunt. Pneumothorax occurred in 8 patients (2 in the TTS group, 4 in the RVIAT group, and 2 in the SMS group). No significant difference was found among the 3 groups. Also, no significant difference was found in the occurrence of pulmonary infection and reoperation because of bleeding after the procedure.

Significant differences were present in the total operative time, CPB time, and crossclamp time in the TTS group compared with the RVIAT and SMS groups (Table 2), although the difference was not significant between the RVIAT and SMS groups. Drainage after surgery was the greatest in the SMS group, and the difference was significant compared with the TTS and RVIAT groups ($P = .001$ and $P = .037$). However, the difference was not significant between the TTS and RVIAT groups ($P = .07$). The intubation time postoperatively was shorter in the TTS group than in the RVIAT and SMS groups, and the difference was significant ($P = .041$ and $P = .001$, respectively). However, no difference was seen between the RVIAT and SMS groups ($P = .156$). The total incision length of the procedure in the SMS group was longer than that in the other groups, and the difference was significant. The ICU stays were shorter for the TTS group than for the other 2 groups, with the longest ICU stays in the SMS group; the difference among the 3 groups was significant. The hospital stay was the least in the TTS group compared with the RVIAT and SMS groups, and the difference was significant. However, the difference was not significant between the RVIAT and SMS groups ($P = .068$).

The overall satisfaction rate for the cosmetic results of TTS and RVIAT was 100% and 96.61% (57/59 patients). The reasons for dissatisfaction were the presence of a keloid at the incision level in 2 patients in the RVIAT group.

DISCUSSION

ASD repair has become a common, routine, and safe procedure through a SMS with CPB and aortic crossclamping. However, most patients, especially females, experience psychological problems because of the large sternal scar caused by SMS. Although the advent of transcatheter closing devices has substantially shifted the treatment of (secundum) ASDs from the surgeon toward the interventionalist, a very large secundum-type ASD, a defect with an insufficient rim to anchor the device, and a fenestrated or aneurysmal interatrial septum have also proved to be less optimal indications for transcatheter closure. Therefore, a variety of minimally invasive cardiac surgical techniques have been developed to close the ASD with the assistance of advanced instrumentation.

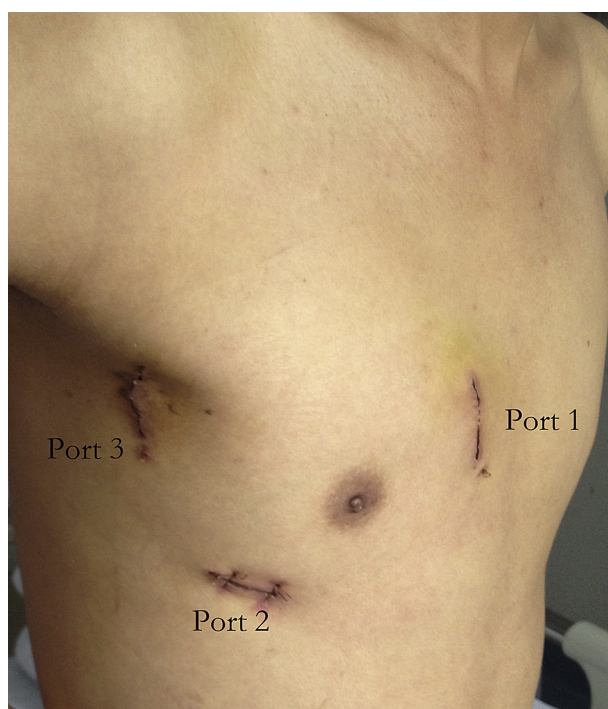


FIGURE 1. Three incisions on the right chest wall.

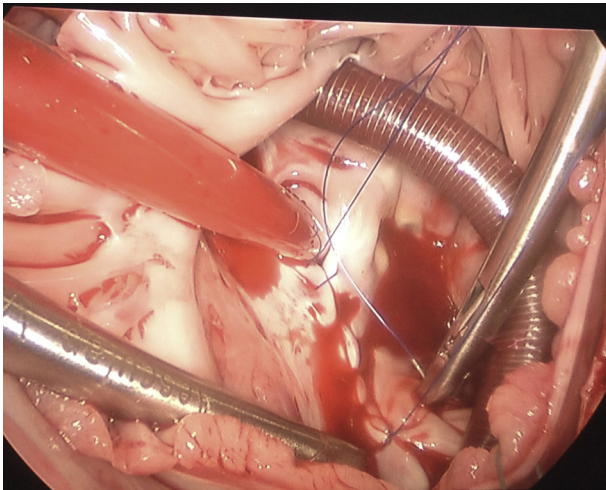


FIGURE 2. Intraoperative view of atrial septal defect that was closed with sutures.

As an alternative to SMS, several groups have reported their experience with RVIAT as the surgical approach. Some have reported excellent results for all ASD types with the RVIAT approach compared with SMS.^{12,13} Our series has supported these findings. Compared with SMS, our minimal RVIAT has advantages. The incision is quite far from the breast tissue and pectoralis major muscle, and no evidence has shown that this approach will cause breast and pectoral muscle maldevelopment. In addition, the surgical scar is concealed and less evident. This technique proved applicable for any type of ASD, including very large secundum-type ASDs and a fenestrated or aneurysmal interatrial septum, with no operative mortality and low perioperative morbidity. In addition, the total operative, CPB, and crossclamp times were not increased using this technique. Most importantly, it reduced the drainage after the procedure, intubation time, ICU stay,



FIGURE 3. The skin incision began at the third intercostal space and extended to the fifth intercostal space along the right mid-axillary line.

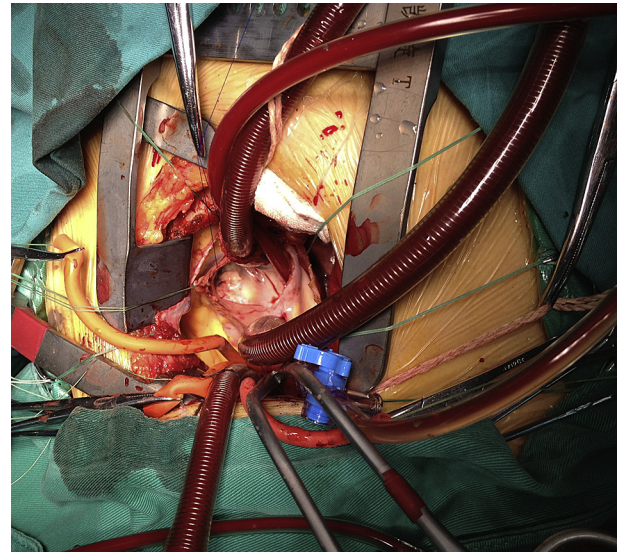


FIGURE 4. Cardiopulmonary bypass was established by cannulation of the aorta and superior and inferior venae cavae.

and hospital stay, without increasing the postoperative complications.

Thoracoscopic ASD closure is another well-accepted technique. Since the early reports on endoscopic repair of congenital heart defects, the use of thoracoscopic techniques for ASD closure has been steadily increasing. Torracca and colleagues¹⁴ reported on 6 patients who had undergone successful robotic ASD closure with rapid postoperative recovery and an excellent cosmetic result compared with those undergoing conventional sternotomy. However, total endoscopic techniques rely on a robotic surgical system, which might increase the cost to the patients. TTS repair of ASDs without robotic assistance is a safe and effective therapeutic option for ASD. Ma and colleagues¹⁵ reported on 40 patients who had undergone totally endoscopic ASD repair without the robotically assisted surgical system. No mortalities and no major complications occurred in the cohort, and this technique combines excellent cosmetic and functional results in almost all patients. Ma and colleagues¹⁶ investigated the quality of life undergoing TTS closure of ASD in 96 patients. The quality of life was assessed using the Medical Outcomes Study Short Form Survey on day 60 after surgery. TTS ASD closure was associated with a faster recovery of physical function and a better quality of life compared with conventional sternotomy. Sometimes, surgeons have been able to complete ASD closure on beating hearts using conventional sternotomy. The question of whether this method can be applied to TTS closure for ASD without the robotically assisted surgical system remained. However, Ma and colleagues¹⁷ have reported that 24 patients successfully underwent nonrobotically assisted TTS closure for ASD on perfused beating hearts and concluded

TABLE 2. Perioperative data

Variable	TTS group (n = 66; group A)	RVIAT group (n = 59; group B)	SMS group (n = 73; group C)	F/chi-square value	P value
CPB time (min)*	87.26 ± 21	41.81 ± 13.97	36.99 ± 10.84	206.47	<.01
Crossclamp time (min)†	32.86 ± 13.36	22.54 ± 9.08	19.23 ± 6.92	33.71	<.01
Total operative time (min)‡	170.3 ± 53.11	93.3 ± 13.9	88.94 ± 14.4	129.3	<.01
Drainage (mL)§	172.2 ± 93.03	205.6 ± 79.2	238.6 ± 95.4	8.364	<.01
Intubation time (h)	6.07 ± 3.72	7.55 ± 3.6	8.55 ± 4.55	6.65	.002
ICU stay (h)¶	23.03 ± 7.76	26.58 ± 8.24	30.23 ± 10.2	11.47	<.01
Incision length (cm)#	5.21 ± 0.63	6.48 ± 1.37	7.45 ± 1.54	55.91	<.01
Hospital stay (d)**	5.34 ± 1.55	6.39 ± 1.79	6.97 ± 2.01	14.45	<.01
Complications (n)					
Reoperation	0	1 (1.69)	2 (2.74)	1.77	.413
Wound infection	0	1 (1.69)	1 (1.37)	1.03	.597
Postoperative pneumothorax	2 (3.03)	4 (6.78)	2 (2.82)	1.63	.442
Mortality	0	0	0	—	—

Data presented as mean ± standard deviation or n (%). TTS, Totally thoracoscopic; RVIAT, right vertical infra-axillary thoracotomy; SMS, standard median sternotomy; CPB, cardiopulmonary bypass; ICU, intensive care unit. *Group A versus groups B and C, $P < .01$; group B versus C, $P = .082$. †Group A versus groups B and C, $P < .01$; group B versus C, $P = .062$. ‡Group A versus groups B and C, $P < .01$; group B versus C, $P = .448$. §Group A versus group B, $P = .07$; group A versus group C, $P < .01$; group B versus C, $P = .037$. ||Group A versus groups B and C, $P = .041$ and $P < .01$; group B versus C, $P = .156$. ¶ICU stay, group A versus groups B and C, $P = .026$ and $P < .01$; group B versus C, $P = .02$. # $P < .01$ among the 3 groups. **Group A versus groups B and C, $P < .01$; group B versus C, $P = .068$.

that the total operative time, CPB time, intensive care stay, and postoperative hospital stay were shorter than those for patients undergoing TTS ASD closure with a cardioplegic arrested heart.

The TTS and RVIAT approaches for closure of ASDs can both achieve cosmetic and functional results. The incision can be hidden, with no significant scars in the front compared with conventional sternotomy. However, the total incision length was longer for patients undergoing RVIAT repair than that for patients undergoing TTS repair for an ASD. This approach has some disadvantages. More time is needed to master the technique. The total operative, CPB, and crossclamp times were much longer in the TTS group than in the RVIAT group. With increased surgeon experience, the operative, CPB, and crossclamp times might decrease. It is easy for the patients undergoing TTS repair to recovery from the surgery, including the ICU stay, hospital stay, postoperative drainage, and intubation time. In addition, some requirements exist for the TTS approach, including patient age >10 years and weight ≥20 kg. Although some investigators¹⁸ have reported that they have successfully performed the technique in small children (age, 5.8 ± 2.1 years; weight, 15.0 ± 4.65 kg), we chose suitable patients for this newly introduced technique. With the development of the surgical technique, we will gradually apply the approach in small children. The RVIAT approach was not restricted by the patients' age and weight. RVIAT can avoid the potential disadvantages of femoral artery cannulation and its complications and the extra expense for special surgical instrumentation. Compared with the TTS approach, the RVIAT approach has a broader application.

One limitation of the present study was that it was a retrospective study, although the demographics, preoperative

symptoms, and ASD size were comparable among the 3 groups.

In conclusion, both the TTS technique and the RVIAT can be performed with favorable cosmetic and accepted clinical results for closing the ASD. The 2 techniques have not resulted in operative mortality to date and have had low perioperative morbidity. They are the promising alternatives to SMS and merit additional study.

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